We Built This City on Rocks and Rolled Steel: A Study of Material Usage and Related Embodied Energy in Austin, Texas, and Antigua, Guatemala

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Abstract

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Looking at today's built environment, we would be nowhere without building materials. But how do we decide what building materials to use in certain projects? There is the choice between regional materials, the local ones sourced from within 500 miles of a job site, and international ones, those that are known for their economic traits and utilitarian uses. Each material carries with it an associated embodied energy, which is the total energy that was put into the material from sourcing to construction. Because of construction experience I've had in both Austin and Antigua, this paper seeks to analyze building material choices between the two cities. It will also propose ideas on how to further incorporate embodied energy into our building codes

The first task is to introduce the topic and give a brief yet broad history of architecture over the last few centuries. The second task is to dive into both cities, looking at common historic building materials and common present-day building materials. The third task is to provide an in-depth explanation of embodied energy and ways to quantify it. Here, the shortcomings of current research will be noted. Finally, I will speak to embodied energy's future potential to influence building codes and incorporate itself into common building practices. In the wake of climate change, changes must be made to our current building method, and I believe that by addressing embodied energy while making initial material selections, a positive change could be made.

Acknowledgements

First, I'd like to express my extreme gratitude to my supervisor, Maria Juenger. Without her continuous support of my thesis-related research, as well as her support in all other facets of life, this project would not have come together nearly as well as it has. Her patience with changes, motivation to push this project to its next level, and guidance throughout the last year and a half are so appreciated. Also, a huge thanks to her for putting me in contact with countless interesting people who she believed would have a stake in this research and further its credibility. Next, I want to thank my second reader, Lawrence Speck, who kept me accountable to the facts. Brainstorming ideas with him truly helped me shape this thesis argument, and his vast knowledge of the building industry was invaluable. Both Dr. Juenger and Professor Speck have pushed me to pursue further education and research in embodied energy, which I plan on doing.

There were many others who contributed to this project, and I'd like to call them out here and express my appreciation for sharing their thoughts and experiences with me. First, Bindy Viviana, who I met on my construction trip to Antigua. She has been my contact on the ground, helping me with Guatemala's history, laws, and common building practices. Bindy has been patient and receptive to my questions and she is to thank for many pictures in this thesis. Next, Gregory Books, was one of the earlier professors I talked to about this topic. His investment in the topic gave me confidence that the idea had potential, and his eagerness to discuss regionalism in rural spheres of life gave me a good foundation on which I built my thesis argument. Third, Catherine Birney, a PhD student at the University of Texas, who told me to consider EIO models and use that as an indicator of associated embodied energy. Finally, I'd like to thank my family and friends who supported me throughout this process by reading chapter drafts, listening to me present this topic, and letting me go off on my soap-box of why regional materials are more environmentally friendly than international ones.

None of this would be possible without you all, and I cannot say thanks enough!

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Introduction

As a proud resident of Austin, Texas, if given the choice between eating a Fredericksburg peach or a run-of-the-mill grocery store peach, which would you pick?

The Fredericksburg peach was grown close to home, and you know that the Sustainable Food Center Farmers' Market at Republic Square has a vendor who carries them. You've had these before and know that the small peach packs lots of rich flavor. The other option is driving to the grocery store and picking up a peach from there. These peaches might be bigger when compared to the Fredericksburg peach, and you may or may not know what kind of flavor is packed into this peach. One more thing that is unclear about the grocery store peach is where it came from. It could be from South Carolina, California, Georgia, or New Jersey, the states that produce the highest number of peaches per year [1]. Both peaches would require a drive, and the main difference is that one is local whereas the other is most likely from farther away. With this new information presented, what would you choose?

If you are leaning towards the Fredericksburg peach, that is the regional choice. It is something you've probably had contact with either growing up or as a snack on the way back from a hike at Enchanted Rock. According to the U.S. Green Building Council, a regional material is defined as a "building material or product (that has) been extracted, harvested or recovered, as well as

[1] AgMRC, "Peaches," University, Agriculture Marketing Resource Cente, March 2019, https://www.agmrc.org/commodities-products/fruits/peaches.

manufactured within a 500-mile (800-kilometer) radius of the project site." [2] Since the Fredericksburg peach was grown around 78 miles away, it fits the description. Taking this concept and viewing a Fredericksburg peach as a local building material, historic buildings made use of these regional materials as the technology to transport huge amounts of materials over a long distance had not come about yet. The intent behind promoting the use of these materials, according to the US Green Building Council, is to reduce the environmental impacts associated with transportation.

On the other hand, if the grocery store peach sounded like a better choice, that is a more 'international style' decision. Referencing the Encyclopedia Britannica, the international style of architecture is described as "the search for an honest, economical, and utilitarian architecture that would both use the new materials and satisfy society's new building needs while still appealing to the aesthetic taste." [3] The grocery store sources peaches from the states that produce the most and are commonly thought of as common peaches since they are shipped to so many locations [4]. Looking at this in terms of building materials, 'international materials' are the concrete, steel, plastic, and glass type materials that have international recognition for being good at what they do and are widely used. They are usually mass-produced and shipped, carrying with them high transportation costs [5].

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[2] "Regional Materials | U.S. Green Building Council," accessed May 8, 2018, http://www.usgbc.org/credits/new-construction-schools/v2009/mrc5.
[3] "International Style | Architecture," Encyclopedia Britannica, accessed May 8, 2018, https://www.britannica.com/art/International-Style-architecture.
[4] AgMRC, "Peaches."
[5] "International Style | Architecture."

Scaling up these concepts for regional and international style of building, this thesis aims to analyze the architectural building materials that have been commonly used in the cities of Austin, TX, and Antigua, Guatemala. The goal is to draw comparisons between material usage, and ultimately see if there are similarities or differences, and why either are present. After comparisons have been made, the concept of embodied energy will be defined and explored in both cities based on what materials are commonly used for building purposes.

History

Rewind many generations ago, to when our ancestors first made structures to inhabit. They used regional materials; whatever materials were readily available and close to them. The technology and resources required to import materials from faraway places were not in place yet, and so our ancestors made do with the earthen materials within arms' reach. Looking at historic structures gives researchers an idea of what was available during that time, allowing them to draw comparisons to present day. It also gives them insight to what building technologies were implemented, from inhabiting caves, to building small structures out of stone or wood.

A local, early Texas architect who made good use of regional materials in the 1900s was named O'Neil Ford. Ford maintained a design philosophy that reflected the ideals of the indigenous people of Texas [6]. He incorporated the artistic style and materials of the historic inhabitants of Texas in structures like 'Little Chapel in the Woods' in Denton, which can still be seen today.

Picture 1: Little Chapel in the Woods [7]

It wasn't until around 1945 that a truly international building style came to be. In Texas, this stemmed from a frustration of wanting functional buildings with more economy in place of the traditional designs that were found everywhere [8]. These 'modern' buildings came about as a result of this frustration and featured machine-produced elements mainly made of concrete, steel, glass, aluminum, and plastic [9]. Asymmetrical components made an appearance, and designers removed many traces of historic details, preferring to cover them up with a more

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[6] Beth Dodd and Elizabeth Schaub, "Texas Architecture: A Visual History - The University of Texas Libraries" (University of Texas at Austin, May 28, 2009), http://legacy.lib.utexas.edu/exhibits/txarch/modern.html.

[7] Texas Woman's University, "Little Chapel In-the-Woods," University, Little Chapel in-the-Woods, March 19, 2018, https://twu.edu/conference-services/reservations-and-information/campus-facilities/little-chapel-in-the-woods/.

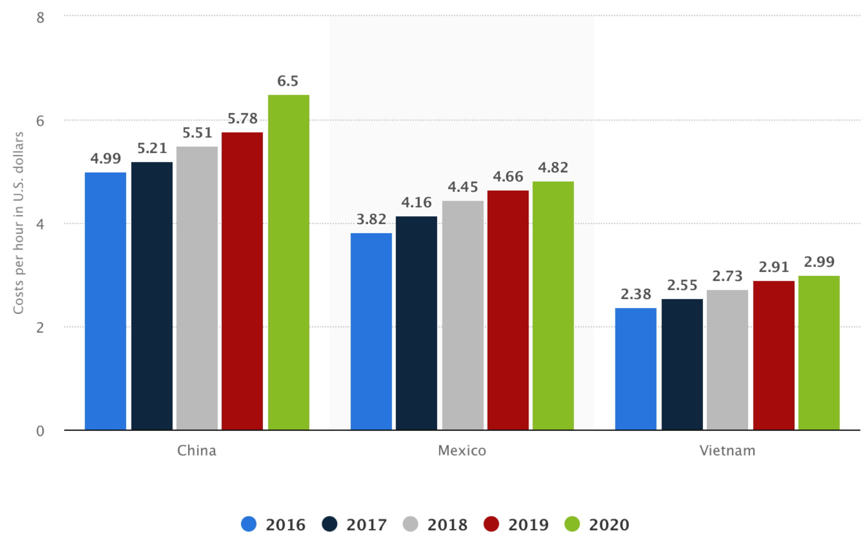
[8] Willard Robinson B., "Architecture," *Texas State Historical Association*, Handbook of Texas Online, June 9, 2010, http://www.tshaonline.org/handbook/online/articles/cmask.

[9] Robinson.

‘international’ façade. Tract housing came up especially in the United States during this time as well, architects and planners hoping to increase the ease and speed at which they erected the more modern residential houses [10].

There were a few other reasons for the increased use of international materials. The first was because labor in other countries was significantly cheaper than labor in the U.S., just as it is today [11]. Looking at current statistics, countries like China, Mexico, and Vietnam all have significantly lower hourly wages than the U.S., which is why so much manufacturing work is outsourced to these countries. China and Mexico have remained main trade partners of the U.S., accounting for 15.7% and 14.5% of the U.S.’s total trade respectively today [12]. The following graph shows how minimum wages in these countries have been increasing over the last few years, and from this we can estimate that the minimum wage in the 1950s was significantly lower than it is today.

[10] Gerald Moorhead, “Overview of Central Texas,” SAH Archipedia (University of Virginia Press, 2012), http://sah-archipedia.org.ezproxy.lib.utexas.edu/essays/TX-01-0001.
[11] NCES, “Manufacturing Labor Costs per Hour for China, Vietnam, Mexico from 2016 to 2020 (in U.S. Dollars),” Statistics, Statista - The Statistics Portal. Statista, April 2017, https://www.statista.com/statistics/744071/manufacturing-labor-costs-per-hour-china-vietnam-mexico/.
[12] US Department of Commerce, “Top Trading Partners - December 2018,” Government, United States Cencus Bureau, December 2018, https://www.census.gov/foreign-trade/statistics/highlights/top/top1812yr.html.



Graph 1: Manufacturing Labor Costs Per Hour in China, Mexico, and Vietnam in U.S. Dollars [13]

The second reason for the increased use of international materials was because of improvements made in transportation and in international shipping. Around the 1950s, transportation on an international scale was in the process of developing fast [14]. The use of freight containers was established around this time, and methods for optimizing loading and unloading methods were coming out [15]. I believe that these improvements, on top of cheaper international labor costs, pushed builders to source more materials from abroad.

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[13] NCES, "Manufacturing Labor Costs per Hour for China, Vietnam, Mexico from 2016 to 2020 (in U.S. Dollars)."

[14] John Edmonds, "The History of the Shipping Container," Freight Basics, General Logistics Technology, Freightos, April 24, 2016, https://www.freightos.com/the-history-of-the-shipping-container/.

[15] "Federal Maritime Commission," in *West's Encyclopedia of American Law* (Encyclopedia.com, 2003), https://www.encyclopedia.com/social-sciences-and-law/political-science-and-government/naval-and-nautical-affairs/marine.

Now, fast forward to the 21st century. The buildings we surround ourselves with are predominantly built in the international style, but there are hints of regionalism mixed in. In the residential sector, regional materials have been making a come-back because new homeowners who build their own houses are not in favor of the lack of decoration and meaning in a purely international style home [16]. Due to this change in thought process, there has been a slow movement towards homeowners taking more initiative and creative liberty in the way their homes are constructed and decorated.

Around 1990, there was a revival of incorporating local climate, historic tradition, and local materials back into the design process [17]. This is not to say that regional materials have completely taken over the residential building sector. Rather it is just to point out that there has been an increase in use of locally-sourced materials.

Although international style is still been the predominant style of building this last half century, regional materials have been making appearances. Looking at recently erected buildings in Austin, the Central Library that formally opened in 2017 is a good example of the use of regional materials. Lueders limestone was one of the main materials used on the façade of this building, and is a material sourced from the heart of Texas [18].

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[16] Robinson, "Architecture."
[17] Robinson.
[18] Aaron Seward, "Austin Central Library: Architectural Crit," *Texas Architect*, April 2018, https://magazine.texasarchitects.org/2018/03/12/austin-central-library-architectural-crit/.

Picture 2: Austin Central Library [19]

The current and previous generations are to thank for this slow shift from international to regional materials. Both are more environmentally conscious generations that have acknowledged the past and made steps to make whatever improvements possible. 'Millennials' as the more recent generation is called, have a higher emotional intelligence and have grown up in an age where common talk revolves around the negative effects of burning fossil fuels, governmental bureaucracy, and how they need to preserve the planet for future generations [20]. The previous generation laid the groundwork for the current solutions being utilized by millennials today. Both generations were made up of task-oriented thinkers, and when confronted with the problem of how to preserve the planet, the previous generation came up

[19] Austin Public Library, "Central Library," Informational, AustinTexas.gov, 2018.
[20] Sarah Landrum, "Millennials And The Resurgence Of Emotional Intelligence," Forbes, accessed May 8, 2018, https://www.forbes.com/sites/sarahlandrum/2017/04/21/millennials-and-the-resurgence-of-emotional-intelligence/.

with policies and standards commonly known as Building Green, LEED, and the U.S. Green Building Council formed in 1985, 1993, and 1993, respectively [21].

An important term that came about with these environmental policies was ‘embodied energy’. It has been a key factor in determining the environmental impacts of certain building materials, and will be discussed in detail in the Chapter titled Embodied Energy.

[21] “BuildingGreen,” accessed May 8, 2018, https://www.buildinggreen.com/.

Central Texas's History

Texas is a region that has had many different rulers, and even ruled itself at one point. One of the earliest, besides the Native Americans that lived in the area, was the Spanish Empire. Early Spanish missionaries were sent to the area in the early 1800s to scout it out and see if the area was inhabited [22]. San Antonio was the first city to be settled in 1718, and the population stayed relatively small due to the pre-existing inhabitants' attitudes as well as the isolation from other Spanish colonies [23] [24].

Due to this isolation, it can be inferred that the architecture of the time was primarily Native American mixed with elements from Spanish culture. Native American architecture is broken into subsets depending on the region where the Native tribe was located. This is because at the time, the only available resources to build with were the ones close to shelter. The tribes of Southern Texas and the Trans-Nueces erected no permanent structures [25]. The tribes of the Trans-Pecos made houses with mud-plastered wood and roofs with mudbrick placed over durable grasses and tree bark [26]. The people of the Panhandle adopted a pueblo culture similar to that of their neighboring states, and were able to construct one story pueblos using masonry

[22] History.com Editors, "Texas," History, History, November 9, 2009, https://www.history.com/topics/us-states/texas.
[23] History.com Editors.
[24] History.com Editors.
[25] Robinson, "Architecture."
[26] Robinson.

items, such as rocks [27] [28]. The people of the Plains had a culture based on buffalo hunting, and needed to move often. Because of this, their structures were temporary and made of hide-covered teepees. Finally, the people of the Mississippi valley in Northeast Texas had more of a permanent lifestyle, and constructed larger structures out of earthen materials, some even 50 feet in diameter [29].

When the Spaniards came in 1718, they brought elements of Spanish architecture along with them, and both integrated this into the pre-existing buildings of the Native Americans, and used their building technologies to construct new buildings [30]. The new buildings mainly consisted of chapels, convents, and similar worship structures that used Spanish and European city planning techniques [31]. The materials they tried to incorporate into Native American buildings included the use of wooden pickets, brush, and mud plaster to create, insulate, and cover walls. They also promoted the use of adobe mid bricks for more than just roofs of structures, and locally-found stone [32] [33].

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[27] Robinson.
[28] Virgil E. Barnes, *Building Stones of Central Texas* (University of Texas at Austin, 1947), http://hdl.handle.net/2027/uc1.b4529920.
[29] Robinson, "Architecture."
[30] History.com Editors, "Texas."
[31] Robinson, "Architecture."
[32] Robinson.
[33] Terry Jordan, *Texas Log Buildings: A Folk Architecture* (Austin: University of Texas Press, 1978), https://books.google.com/books?id=tTBMAgAAQBAJ&dq=popular+building+stones+central+texas&lr=.

The Alamo is a good example of a structure built during this transition time. Resembling the Baroque style that was popular in Europe at the time, it was originally the Chapel of the Mission San Antonio de Valero, and was nicknamed 'The Alamo' because it stood in a grove of cottonwood trees, and 'alamo' is Spanish for 'cottonwood' [34] [35]. It used locally-quarried limestone which was in line with the settler's goals of incorporating local materials into regular building construction practices [36]. Limestone is prevalent in the current building materials and methods present in central Texas, as it is still one of the most commonly used materials.

Moving forward to the 20th century, designers went back and forth between wanting to utilize the regional style that was prevalent in the past and the modern style, which was increasingly uniform throughout developed nations. The École de Beaux Arts in Paris influenced modern designers and pushed them to use a more unified method. This led to regional characteristics disappearing to make room for this 'uniform' front [37]. Improvements in transportation and in the availability of cheap labor also helped with this switch from regional to international materials [38]. The critics who were in favor of designing using regional materials instead of international ones had issues with this change, and some kept building in their preferred style.

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[34] The Editors of Encyclopaedia Britannica, "Alamo," Encyclopædia Britannica, October 26, 2018, https://www.britannica.com/place/Alamo.
[35] The Editors of Encyclopaedia Britannica.
[36] Alamo Staff, "The Alamo," Informational, Tourist, The Alamo, accessed March 1, 2019, http://www.thealamo.org/remember/structures/buildings/index.html.
[37] Robinson, "Architecture."
[38] NCES, "Manufacturing Labor Costs per Hour for China, Vietnam, Mexico from 2016 to 2020 (in U.S. Dollars)."

One architect that falls into this category is O'Neil Ford, who was mentioned in the Introduction chapter.

After World War II, there was another push for more economical buildings with functional, rather than aesthetic, designs. This, aided with the blooming of international style around 1945, called for the elimination of ornamentation and rejection of historic styles [39]. The war efforts had shown the world how efficient factories and machine manufactured parts could be, and this was probably the mentality designers found themselves in, craving that speed and ease. Tract housing was a product of this time, as was the increased use of concrete structural systems, steel, laminate wood, aluminum, glass, and plastics [40].

Again, the critics expressed concern that this modern architecture was too bland, and did not have enough depth; it did not meet their standard for decoration with meaning [41]. During this movement, in Texas there were two main agencies that fought to keep historic elements preserved on buildings, the San Antonio Conservation Society and the Texas Historical Commission [42] [43]. They passed legislation in the mid to late 1900s and created programs to help

[39] "International Style | Architecture."
[40] Robinson, "Architecture."
[41] Robinson.
[42] Lewis Fisher, "SAN ANTONIO CONSERVATION SOCIETY," Independent Non-Profit, Texas State Historical Association, June 15, 2010, https://tshaonline.org/handbook/online/articles/gas01.
[43] Truett Latimer and Laurie Jasinski, "TEXAS HISTORICAL COMMISSION," Independent Non-Profit, Texas State Historical Association, June 15, 2010, https://tshaonline.org/handbook/online/articles/mdt17.

preserve and restore historic buildings in the area [44] [45]. An example of the types of projects the Texas Historical Commission took on was the Texas State Capitol in Austin [46].

In present day, buildings that make use of all the previously mentioned styles can be found throughout Central Texas. It is a tangible aspect that adds to Texas's detailed history. But in this period of architectural styles blending together, where do we fall in terms of material usage? Do they focus on regional materials or more international ones? To answer this, we need to know what the regional materials of Central Texas are.

Regional Materials in Central Texas

In terms of material selection and usage, Texas is located within the United States, a developed nation. This is important to note as it shows that the U.S. has the means to purchase and use international materials like steel, concrete, glasses, and plastics. Because of this ability, looking around, those are some of the main materials we see on display, especially in the commercial sector.

The residential sector, on the other hand, seemingly has more variety to offer. As times change, so do the tastes of home owners. Since there is a mix of home-owners buying land and building their own homes and home-builders building homes based on what they believe will sell, there is a big mix of building styles in Central Texas, Austin specifically. I hope to focus on the last 50

[44] Fisher, "SAN ANTONIO CONSERVATION SOCIETY."
[45] Latimer and Jasinski, "TEXAS HISTORICAL COMMISSION."
[46] Latimer and Jasinski.

or so years in this chapter in the context of Central Texas's changing tastes. This is also referred to as the time when "modernism's lack of ornamentation and functionalist designs gave way to an architectural style based on historical precedents in the Postmodern era" [47].

Climate and historic building traditions were re-introduced to the design process around the 1900s [48]. This meant looking at what the original settlers and indigenous people used and trying to honor their material choices. I speculate that during this time of conscious construction, homeowners had a feeling of increased connectedness to the land they were living on. This is due to the fact that the materials being used to make their living structures were the same as the materials found naturally around them.

Marble, granite, limestone, clay, and timber are all materials that are available in abundance in the Central Texas region and are also more or less the materials the indigenous people and Spaniards used as they built infrastructure, as mentioned earlier [49].

As time passed, the people of this region made concrete out of limestone, river gravel, and other aggregate, standardizing this practice. The Colorado River flows through Central Texas, and there are other bodies of water scattered throughout that provide access to river gravel. In fact, in Austin, there is a park called Reed Park which is home to a lime kiln. Its name is the

[47] Dodd and Schaub, "Texas Architecture: A Visual History - The University of Texas Libraries."
[48] Moorhead, "Overview of Central Texas."
[49] Barnes, *Building Stones of Central Texas*.

Taylor Lime Kiln, and was built in 1871 [50]. It has an older façade from the way that the bricks are laid out, highlighting its age. Limestone from a nearby quarry was brought to this kiln, where it was then heated at very high temperatures, creating lime that was vital to the concrete making process. Because of the central location of this kiln, and the abundance of limestone in the region, concrete became one of the most popular regional material choices around this time. It was a major factor in Austin's early economy [51].

Another kiln in the area was in San Antonio, located near the present-day San Antonio Zoo and Japanese Tea Gardens. In 1901, the public park this area is in was officially opened, and soon after, the Alamo Cement Company began to use the quarry to the west of this City-owned Park[52]. Similar to Taylor Kiln in Austin, this quarry was going to supply the limestone to then be fired and used in cement production.

Wood is another material that contributed to the early economies of Austin and Central Texas. Coming with influences from Europe, the material has been around for a long time now, but its popularity has depended on the time. The indigenous people of Central Texas used it in most of their structures, as is outlined at the beginning of this chapter, and the usage was heightened

[50] Texas Historical Commission, *Taylor Lime Kiln No. 1*, 1983, Park Sign, 1983.
[51] Texas Historical Commission.
[52] San Antonio Parks and Recreation, "Japanese Tea Garden," City Government, City of San Antonio, accessed March 26, 2019, https://www.sanantonio.gov/ParksAndRec/Parks-Facilities/All-Parks-Facilities/Parks-Facilities-Details/artmid/14820/articleid/2912/japanese-tea-garden.

once the settlers came from Europe [53]. In today's world, wood can be seen on most construction sites as a framing material and has structural applications as well. There is a growing interest in the material on a global scale as it is being used for new applications, like skyscrapers, pushing it in terms of its structural capabilities [54]. In Central Texas, it is available in abundance in the Hill Country Region, and so is considered a 'regional material'.

Picture 3: Wood Framing on a Building Undergoing Construction

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[53] San Antonio Parks and Recreation, "Japanese Tea Garden," City Government, City of San Antonio, accessed March 26, 2019, https://www.sanantonio.gov/ParksAndRec/Parks-Facilities/All-Parks-Facilities/Parks-Facilities-Details/artmid/14820/articleid/2912/japanese-tea-garden.

[54] Michael Ramage and et. all, "The Wood from the Trees: The Use of Timber in Construction," *Renewable and Sustainable Energy Reviews* 68 (February 1, 2017): 333–59, https://doi.org/10.1016/j.rser.2016.09.107.

Marbles and granite can be clumped together under the umbrella term of stone. In day-to-day life, stones are found almost everywhere, from helping create concrete sidewalks to being a main material in residential housing. They have stayed popular throughout the years of the indigenous well into present day. The State Capitol building is a good example of locally sourced stones being used for a myriad of purpose. The exterior walls are made of red granite quarried in Burnet County, and the interior walls are made of Texas limestone, most likely sourced from the same quarry that was used to transport limestone to the Taylor Kiln, mentioned earlier [55] [56]. The original floors of the Capitol building were made of clay tiles, glass, and wood, and later replaced by a material called terrazzo, mainly made up of Texas marble aggregate [57]. Since the Capitol is such a trademark building of Texas and represents hard-earned independence, the regional materials serve to remind the people who walk by and work in that building of the connection they all share to the State.

[55] State Preservation Board, "Capitol History," Government, Texas House of Representatives, February 14, 2019, https://house.texas.gov/about-us/capitol-history/.
[56] Barnes, *Building Stones of Central Texas*.
[57] State Preservation Board, "Capitol History."

Picture 4: Texas State Capitol [58]

Picture 5: Interior Marble in the Texas State Capitol [59]

[58] Sarah Karney, "A Brief History of the Texas State Capitol Building," *Culture Trip* (blog), March 4, 2019, https://theculturetrip.com/north-america/usa/texas/articles/a-brief-history-of-the-texas-state-capitol/.

[59] Jill Bartek, "Photo Saved from Jill Bartek," Photos, Design, Pinterest, n.d., accessed May 8, 2019.

Clay in Central Texas is collected and used for more than just pottery. It is a major component of bricks, which were prevalent in the early building history of the region. Adobe is the Spanish word for 'sun-dried brick' and was a popular material during the time of Spanish colonization, and the influence has lived on past their time [60]. Brickwork is regarded as one of the fundamental construction types in contemporary building, which is why the industry has been around for so long [61]. Around Central Texas, many residential structures have brick façades, the house I grew up in included. Clay is found in almost all regions of Texas and so can be sourced close to wherever the job site may be, making the travel times short and not troublesome [62].

Steel is the last material I want to elaborate on in this section. It is a well-known structural material, and is the backbone of many buildings all over the world, as well as in Central Texas. Steel gained its popularity in the 1920s and 1930s when international style was the prevalent design philosophy [63] and has stayed in practice ever since. For large structures, it is the structural material of choice, and there are steel fabrication plants scattered throughout the state, as a quick Google search will show.

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[60] "Word Reference," Online Language Dictionary, Word Reference, March 1, 2019, http://www.wordreference.com/es/en/translation.asp?spen=adobe.
[61] "GreenSpec: Timber and the Environment," 2018, http://www.greenspec.co.uk/building-design/timber-and-the-environment/.
[62] Texas State Historical Association, *Texas Almanac*, 2018th–2019th ed., accessed March 4, 2019, https://texasalmanac.com/topics/environment/soils-texas.
[63] "International Style | Architecture."

A Good and Bad Example of the Use of Regional Materials

Within the city of Austin, there are pockets of mostly modern buildings, and there are pockets of mostly older structures. But in general, both kinds of buildings are interspersed throughout the city limits.

Battle Hall is an example of a building that exemplifies what it means to use regional materials in a structure. Today, it stands tall on the University of Texas campus and is used as one a study space by many students as well as the Architecture and Planning Library for architecture students [64]. The need for a new library came about in 1909 when the main library of the university was facing overpopulation issues and requests from students to carry more library material [65]. The architect in charge of the new library was named Cass Gilbert, an American architect trained in the style of the renowned Beaux Arts [66]. During his time working with the University, he only designed two buildings, but his influence surpassed the designs and changed the way that architects after Gilbert built in the region [67]. He used a style referred to as modified Spanish Renaissance, which has now become the "signature motif of the Forty Acres"[68], the 'Forty Acres' referring to the University Campus. Looking at Battle Hall, Gilbert

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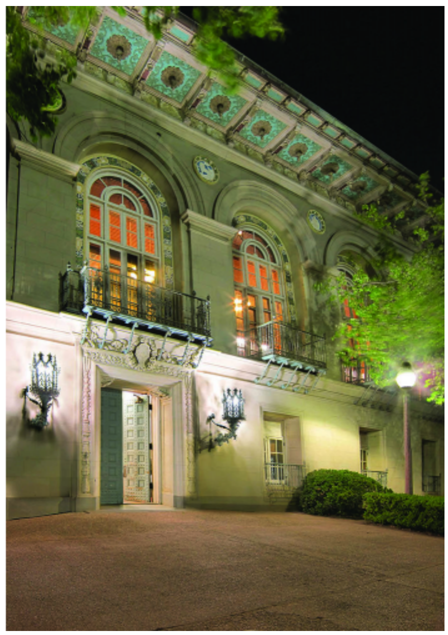
[64] UT School of Architecture, "A WITNESS TO HISTORY: Battle Hall and the Past, Present, and Future of the School of Architecture," University, Texas Architecture, accessed April 13, 2019, https://soa.utexas.edu/battle.
[65] UT School of Architecture.
[66] Lawrence Speck, *Landmarks of Texas Architecture*, 1st ed. (University of Texas Press, 1986), https://larryspeck.com/writing/battle-hall-university-of-texas-at-austin/.
[67] Barbara Christen and Steven Flanders, *Cass Gilbert Life and Work: Architect of the Public Domain* (New York: W. W. Norton, 2001).
[68] UT School of Architecture, "A WITNESS TO HISTORY: Battle Hall and the Past, Present, and Future of the School of Architecture."

made extensive use of “rich color in the painted wooden cornice and terra cotta medallions and window surrounds” [69]. His main building material was a specific cream-colored limestone that came from Cedar Park [70]. Cedar Park is around 20 miles away from Battle Hall according to Google Maps, and so counts as a regional material by the definition earlier in the chapter.



Picture 6: Battle Hall at Night [71]

On the other hand, a building that could have made better use of regional material is called the Frost Bank Tower, located in the heart of Downtown Austin. The structure has added to the Austin skyline and is a characteristic building of the city, but the material choice doesn’t reflect what is readily available. It makes use of over 200,000 square feet of a silvery blue color glass

[69] Speck, *Landmarks of Texas Architecture*.
[70] Speck.
[71] UT School of Architecture, “A WITNESS TO HISTORY: Battle Hall and the Past, Present, and Future of the School of Architecture.”

that has only been used in one other building in the world, the Reuters Building [72]. It does make use of Texas limestone on the lower floor's cladding, but the primary façade materials are plain steel and clear glass, which are two main international style materials that take away the connection to the city the building could have had [73].

Picture 7: Frost Bank Tower [74]

[72] James, "Austinites Weren't Always So Sure About Downtown's Iconic Frost Bank Tower," News, Tower, March 7, 2019, https://austin.towers.net/austinites-werent-always-so-sure-about-downtowns-iconic-frost-bank-tower/.
[73] James Rambin, "Austinites Weren't Always So Sure About Downtown's Iconic Frost Bank Tower," News, Tower, March 7, 2019, https://austin.towers.net/austinites-werent-always-so-sure-about-downtowns-iconic-frost-bank-tower/.
[74] Rambin.

Antigua, Guatemala's History

During the first millennium, A.D., the land of present day Guatemala was home to the ancient Mayan civilization [75]. The name 'Guatemala' has two meanings, depending on the language from which it is translated to English. If it is translated from Quauhtemallan, it means "land of trees", and if it is translated from Guhatezmalha, it means "mountain of vomiting water" [76]. The ancient Maya settled in, creating a life for themselves well into the 1500s. In 1524, the first Spanish colonizers arrived, pushing their way of life onto the locals till 1821, when Guatemala gained its independence [77]. The Spanish brought with them a distinct culture, way of life, city planning, and building technologies.

Before diving into the building technologies that the Spanish brought with them, I'd like to give some background on the region. Guatemala is a country located in Central America and has a land mass of about half that of Texas [78] [79]. It has a tropical climate and can have hot and humid summers, like those we experience in Texas, as well as cooler conditions in the Highlands [80]. It is split up into three regions based on the mountain ranges and volcanoes in the area, and those are: The Mountainous Highlands, The Pacific Coast, south of the mountains, and The Northern

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[75] CIA, "CENTRAL AMERICA: GUATEMALA," Fact Sheet, cia.gov, accessed March 11, 2019, https://www.cia.gov/library/publications/the-world-factbook/geos/print_gt.html.
[76] Thomas Anderson et al., "Guatemala," in *Encyclopædia Britannica* (Encyclopædia Britannica, inc., February 4, 2019), https://www.britannica.com/place/Guatemala/Civil-war-years.
[77] Rich Polanco, "Iglesia De La Merced Antigua Guatemala: 2018 Visitors Guide," *OK Antigua* (blog), 2016, https://www.okantigua.com/iglesia-la-merced-antigua-guatemala/.
[78] CIA, "CENTRAL AMERICA: GUATEMALA."
[79] CIA.
[80] CIA, "CENTRAL AMERICA: GUATEMALA."

Petén Lowlands, usually shortened to just 'Penén' [81]. It has many active volcanoes as it is located on the 'Ring of Fire', and a mean elevation of 759m, about 2500ft [82]. Lastly, looking at the demographic that lives in the country, around 60% are of Spanish and European descent, and around 39% are of Mayan descent [83].

Guatemalan architectural styles can be broken down into three major sections: that of the Mayan, of the Spanish, and finally post-colonial. Mayan architecture is still prevalent in some areas of Guatemala, for example in Tikal in the Petén region [84]. The builders of the time admired and sought to emulate the other cultures around them, and thus their structures had influences from Mesoamerican groups, like the Olmec and the Teotihucan [85]. Material wise, local limestone was used in certain projects, while local sandstone and volcanic ash were used in others [86]. Tikal and Palenque are areas in Guatemala where one can see limestone in Mayan architecture, Quiriguá is where sandstone in Mayan architecture is on display, and Copan is where one can see an extensive use of Volcanic ash [87].

Petén has natural limestone deposits, which made it an easy to access material for Mayan projects [88]. The region of Petén is also rich in forested areas, so lumber was sourced from here

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[81] CIA.
[82] CIA.
[83] CIA.
[84] Mark Cartwright, "Maya Architecture," in *Ancient History Encyclopedia*, September 20, 2015, https://www.ancient.eu/Maya_Architecture/.
[85] Cartwright.
[86] Cartwright.
[87] Cartwright.
[88] Anderson et al., "Guatemala."

and used for building purposes [89]. It was also used to fire lime for future use in cement production [90]. Cement was used to make concrete and if possible, mortar, as the alternative was using a less sturdy adhesive, mud [91]. Limestone, lumber, and concrete are all on display in Tikal, as are thatched wooden roofs, and high relief carvings and sculptures for decoration purposes [92].

Tikal used to be known as 'Yax Mutal' which means 'Place of Whispers' [93]. It was the political and economic hub of the Mayan world at the time, and housed multi-roomed structures that served as temples, palaces, residences, ballgame courts, as well as tombs [94]. 'Dinteles' is the name the people who lived in Tikal gave to the finishes placed on doors and roofs throughout the region [95].

[89] CIA, "CENTRAL AMERICA: GUATEMALA."
[90] Anderson et al., "Guatemala."
[91] Cartwright, "Maya Architecture."
[92] Cartwright.
[93] Cartwright.
[94] Cartwright.
[95] Bindy Viviana, Email with Bindy Viviana, Email, March 31, 2019.

Picture 8: Tikal [96]

As time went on and the building technologies of the Mayans improved, they started to create structures that used a base made of stone, had wooden columns, and were finished with both mud and the roots of palm trees [97]. There are still buildings around in more rural areas of Guatemala that make use of this building form [98].

Picture 9: Moving Forward with Building Technologies [99]

[96] Viviana.
[97] Viviana.
[98] Viviana.
[99] Viviana.

During the time of Spanish rule from 1519-1821 [100], similar to what happened in Central Texas, colonizers brought their own styles and methods of building and city planning. Adobe, a sunbaked mud brick, was pushed on the indigenous Mayans, who had used it sparsely prior to the Spaniards' arrival [101]. In terms of city planning, a central square was established in each of the bigger cities to act as the main gathering point for the people. These central squares were dominated by church and government buildings, most likely to highlight how important both church and state were, since they were in the heart of each city [102].

The style of building under Spanish rule was called "Barroco Antigueño" [103], which translates to the Antiguan style of the Baroque period. The United Nations Educational, Scientific and Cultural Organization (UNESCO) team defined some of the key characteristics of this style as including:

> … the use of decorative stucco for interior and exterior ornamentation, main façades with a central window niche and often a deeply-carved tympanum, massive buildings, and low bell towers designed to withstand the region's frequent earthquakes [104]

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[100] Building Bridges Coalition, "An Introduction to Guatemalan Architecture," *Build Abroad* (blog), accessed March 11, 2019, https://buildabroad.org/2017/05/31/guatemalan-architecture/.
[101] Safari the Globe, "Architecture of Guatemala," Cultural Information, Safari the Globe, March 2013, http://www.safaritheglobe.com/guatemala/culture/architecture/.
[102] Safari the Globe.
[103] Building Bridges Coalition, "An Introduction to Guatemalan Architecture."
[104] UNESCO, "Antigua Guatemala," Informational, UNESCO, accessed March 11, 2019, https://whc.unesco.org/en/list/65/documents/.

A good example of a building constructed during the Barroco Antigueño period is called Iglesia de la Merced. It was started in 1749 and finished in 1767 by architect Juan de Dios Estrada [105]. De Dios adapted the original church design from a much bigger area of worship into a lower, more condensed structure, that would still meet the needs of the Mercedarian group who commissioned it [106]. To do this, he "lowered typical baroque, airy ceilings down … to two-thirds lower … also added thick walls that were up to a meter wide and thicker buttresses" [107]. The main goal was to fit the style of Barroco Antigueño and ensure that the structure would be able to resist earthquakes as well as withstand volcanic eruptions and hurricanes [108].

The reason that Iglesia de la Merced is in Antigua is because at this point, Antigua was the capital of Guatemala, and served as the "cultural, economic, religious, political, (and) educational center" [109].

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[105] Polanco, "Iglesia De La Merced Antigua Guatemala: 2018 Visitors Guide."
[106] Polanco.
[107] Polanco.
[108] UNESCO, "Antigua Guatemala."
[109] UNESCO.

Picture 10: Iglesia de la Merced, Antigua, Guatemala

Guatemala today has had some modernization in terms of building materials, but this has centered itself in Guatemala City [110]. Other cities are lagging in terms of building technology improvements and have not developed a modern or postmodern style. In Antigua, for example, a ‘neo-colonial’ or ‘Antigua style’ of building is gaining popularity, but this is mainly to meet the demands that increasing tourism poses to the city [111]. New buildings are being erected on the sites of older, more historic ones, and the historical integrity of the city is starting to suffer due to his growth [112].

[110] Safari the Globe, “Architecture of Guatemala.”
[111] UNESCO, “Antigua Guatemala.”
[112] UNESCO.

In rural areas, though, regional styles are still predominant. Guatemala has a nearly even split between people who live in developed regions and who live in rural ones, so it is safe to say that a high degree of regionalism has been maintained [113]. It is considered a poor country, and this is one of the main reasons that the country has not seen as much modernization as say Central Texas has [114]. In a conversation with Gregory Brooks, a professor in the Architectural Engineering department at the University of Texas at Austin, he voiced his opinion that developing countries have been able to maintain more of their regional characteristics, when compared to developed countries [115]. The International Building Style did not have as much of a hold over the country, and thus there are not an overwhelming number of similar structures made of steel, concrete, and glass [116]. Lumber, especially pine, is exported from the tropical forests of Petén, as well as from the coniferous forests of the Highlands to be used in local construction [117].

In the rural sphere, it is common to see homes made of adobe, the sunbaked mud brick that the Spanish colonizers pushed. Also, wooden planks, thatched roofs, tiles, and corrugated metal are common wall and roofing materials [118]. Floors are usually made of earthen materials [119].

[113] Anderson et al., "Guatemala."
[114] CIA, "CENTRAL AMERICA: GUATEMALA."
[115] Gregory Brooks, Interview, In-person, April 2018.
[116] "International Style | Architecture."
[117] Anderson et al., "Guatemala."
[118] Anderson et al.
[119] Anderson et al.

Regional Materials in Antigua, Guatemala

In terms of material selection and usage, Antigua is located within Guatemala, a developing nation. Just as it was important to note that Central Texas lies within a developed nation, it is equally important to realize that a comparison is being drawn to Guatemala, a country that is developing. Due to the fact that the two countries were not developing at the same pace, I speculate that is one of the main reasons that international materials like steel, concrete, glass, and plastic, did not have as much of a hold in Guatemala as they did in Central Texas, for example. Since they didn't stick, much of the main infrastructure of Guatemala, and Antigua in specific, is not made up of them, opting to use more regional materials instead [120]. A higher degree of regionalism has been maintained in Antigua because of this, and even today some traditional practices are being followed [121] [122].

As has been discussed in the previous section, the first architectural period, that of the Mayan civilization, set the groundwork for what regional materials would be used heavily in the region. The raw materials were limestone and lumber, which were used to make cement and wooden columns and beams for structural systems as well as for adhesive. The Spanish colonizers who came after and developed the "Barroco Antigueño" style played off the materials and technologies of the Mayan people, adding a few materials of their own to the mix. The main one was adobe, and the building philosophy the Spaniards brought with them was about city planning, emphasizing that cities needed a big central square along with a church. The current

[120] Viviana, Email with Bindy Viviana.
[121] Brooks, Interview.
[122] Viviana, Email with Bindy Viviana.

architectural period we are in today varies slightly from urban to rural region. In the rural ones, the practices of the Maya and Spanish are continued, and small hoses made with adobe, wooden columns, and corrugated metal are still widespread [123]. In the more urban centers, there have been small changes towards more modern buildings [124]. This is seen through ornamentation on building façades, as well as in choices of imported international materials, like steel, an item not commonly produced in Antigua [125].

Speaking to a local Guatemalan contractor who works closely with projects in Antigua, she reinforced the classification of certain materials with time periods mentioned in the previous paragraph. According to her, the shift from older styles to more modern ones is currently underway. A material she says that has been gaining popularity in the rural areas of the country is cinderblock, also known as a Concrete Masonry Unit, or a CMU. This is being used in tandem with Spanish adobe, as well as the wooden structural systems that were made popular under the Maya.

Why Compare Antigua?

During the 2017-2018 academic year, I had the chance to work on a team of engineers and social workers to collaborate with a NGO located in Jocotenango, Guatemala, about 10 minutes out of Antigua by car. The NGO is called Garden of Hope, and is a permaculture garden aimed at

[123] Viviana.
[124] Viviana.
[125] "International Style | Architecture."

giving young children of the area a space to develop important life skills, and understand the importance of good nutritional value [126]. The kids are given a space to learn how to grow fruits and vegetables, and are also taught lessons in the outdoor classroom pertaining to nutrition and permaculture principles. Malnutrition is one of the main problems that the population of Guatemala struggles with [127], and so my team and I were tasked with aiding Garden of Hope in their endeavor to increase awareness of good nutritional habits. The way we did this was by building them a teaching kitchen, which is currently being used to show the children how to sustainably cook the vegetables that are grown in the garden.

My team and I travelled to Jocotenango during the summer of 2018 to construct this teaching kitchen, with the help of local contractors from Antigua. Working with the locals gave us all insight to how structures are usually built in the area, and highlighted differences in building methods. This is the reason I chose to compare material usage in Antigua, specifically.

It was fascinating to learn how people in Antigua handled construction, and to see what the differences and similarities were to construction philosophies in the U.S. There were some local equivalents of Home Depot in Antigua, called El Mastil and Acuario. Most construction projects, ours included, bought materials from here. Construction philosophy wise, smaller scale buildings, like the one-story kitchen we built, didn't call for machine-mixed concrete, rather

[126] Garden of Hope, "Garden of Hope," Informational, Garden of Hope, 2014, http://www.gardenofhopegt.com.
[127] CIA, "CENTRAL AMERICA: GUATEMALA."

hand-mixed concrete, which we made on site by eyeballing the consistency and using the contractors' judgement. Rebar was used generously, giving the concrete the required strength, as well as providing a factor of safety in case the mixing consistency wasn't ideal. Building codes were not used as strictly as they are followed in the U.S., and the contractors went off the plans the team and I had made based off U.S. codes. Wood framing was used for the whole building, which is typical of smaller scale buildings in the area. In terms of the roofing material, most one-story structures utilized corrugated metal. It came in a variety of color options, and the right color was selected based on how much sunlight was intended to enter the main area. The finishing material in the U.S. that is commonly seen is called Tyvek, and the Guatemalan equivalent was called Durock. PVC pipes were used for piping and plumbing in and out of the building.

A Good and Bad Example of the Use of Regional Materials

Generally speaking, the use of regional materials increases with distance from Antigua's city center. These areas tend to be more rural, and as we have already discussed in this paper, rural areas tend to keep a higher degree of regionalism when compared to their more urban counterparts [128].

[128] Brooks, Interview.

Another factor that has pushed the use of non-regional materials is because of the earthquake that hit Guatemala in 1976. The earthquake was a 7.5 on the Richter Scale [129] and during the aftermath, there was a change in building mentality for a lot of people. Adobe-walled houses crumbled, and the damage done to the rural areas of Guatemala was intense, totaling in over 22,000 deaths [130]. The more well-off houses, usually located in cities, were not as badly affected as the simpler ones, as they were built with extra reinforcement and more earthquake-resistant materials [131]. Speaking with someone who works closely with building codes in Antigua, she said that there were new construction laws that went into effect after 1976, as well as a push to create an institution that focus on researching the seismic, volcanic, meteorological, and hydrological activity in the region [132]. Within this, my contact told me that construction codes were amped up, and reinforcing all residential structures came into common practice.

Moving into the countryside of Antigua, in Jocotenango specifically, the kitchen that my group and I designed made use almost solely of regional materials. From the broad design philosophy, we took into account what normal practice in the region was, and so based the design off of pre-existing structures the community was already familiar with. Next, we considered ventilation patterns and roof sloping, trying to ensure maximum airflow in and out of the

[129] Deborah Levenson, "Reactions to Trauma: The 1976 Earthquake in Guatemala," *International Labor and Working-Class History* 62 (2002): 60–68, www.jstor.org/stable/27672805.
[130] Levenson.
[131] Levenson.
[132] "Creáse el instituto de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH)." (1976), https://leyes.infile.com/index.php?id=181&id_publicacion=23683&cmd=login#comprar_membresia.

building. In terms of material usage, the river gravel used in concrete mixing came from local rivers close to Jocotenango, and the cement was manufactured locally, making use of the large limestone deposits available in the region. The pine wood that was the basis of the kitchen's structural framing came from the northwest of Guatemala, from the regions of Quiche and Alta Verapaz [133].

Picture 11: Wood Framing During Construction in Antigua

Looking within the city of Antigua, some modern homes are examples of the use of more international styles and materials, as the following picture will show. From first glance, there is no adobe used, a classic regional material. There is also no visible wood paneling, and judging

[133] Viviana, Email with Bindy Viviana.

by the size of the house, Guatemalan building codes might have specified steel framing [134]. Stones and concrete seem be the main materials on this building, and there is a high degree of ornamentation in patterns that are not historically associated with the region. These are all speculations as I have not seen the home in person, just through photos.

Picture 12: Less Regional Building Methods in Antigua [135]

[134] Viviana.
[135] Viviana.

Embodied Energy

Let me tell you the story about my zebra stuffed animal, pronounced *zeh-bruh*. Zebra was one of the many stuffed animals I collected as a child, and he was from New Zealand. It did not matter how big they were, what outlandish colors they might be, or even if I knew if the animal was real or not; I was a young stuffed animal hoarder. Having come all the way from New Zealand, Zebra had an 'awe' factor associated with him, and even had a special spot in my room where he would sit. Another one of my favorites to this day is named Sparky, my beagle stuffed animal who has been with me since the young age of 7. It was a gift from a childhood friend and has lasted all these years. Being from Austin, Sparky didn't have the same 'awe' factor Zebra did, but Sparky had more in common with the dogs of Austin, and with my other friends' stuffed animals at the time. Zebra was unique and foreign, whereas Sparky was local and more common.

If we shift focus and think of these two stuffed animals in terms of building materials, they could translate into a unique kind of stone from New Zealand and limestone from Austin. Living in Austin, we see an abundance of limestone from driving up and down the Capital of Texas Highway, to the real Capitol of Texas that has interiors made of locally sourced limestone [136]. If we draw on this childhood story and imagine that I was trying to procure materials to build a house of my own, the logic I had as a child would be to use the unique stones from New Zealand in my design rather than utilize the limestone readily available. The thought that the

[136] State Preservation Board, "Capitol History."

New Zealand rocks would take much more effort to procure and transport, when compared to the local limestone, would not have crossed my mind.

A good example of this that is found in Austin is located on The University of Texas (UT) campus. Located on San Jacinto Boulevard between East Dean Keeton Street and East 24th Street, the Engineering Education and Research (EER) Center was officially opened in the Fall of 2017. The idea was played around with for over ten years and the intention behind the EER was to build a building that represented what UT Engineering stood for, and that identified a single building to be the 'home base' for UT Engineering [137] [138]. Drawing inspiration from the other buildings on UT campus, the EER utilized the local architecture around it as well as locally sourced materials. An article about the design quoted the designers saying, "'The building materials hearken to the traditional campus with the use of local Texas limestone and ornamental metalwork in stainless steel and zinc'" [139].

An element of the EER that raised eyebrows and urged the designers to ask for outside help was the spiral staircase located in the north-east corner. The initial idea was to have an enclosed space around the stairs, but after that was deemed "too intrusive" [140] the idea came

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[137] University Communications, "New Era Begins with Opening of 430,000-Square-Foot Engineering Education Building at UT Austin," *UT News*, September 28, 2017, https://news.utexas.edu/2017/09/28/new-era-begins-with-opening-of-engineering-building/.
[138] University Communications.
[139] Jenna McKnight, "Giant Metal Lattice Fronts Atrium of Texas Engineering School by Ennead," *De Zeen*, January 30, 2018, https://www.dezeen.com/2018/01/30/engineering-education-research-center-university-texas-austin-ennead/.
[140] Shruthi Avantsa, "Welcome Home, Cockrell," *Vector Engineering Magazine*, Fall 2017.

about for an interior lattice. To aid in stability, the designers knew that the ratio of steel to openings had to be greater closer to the bottom, but wanted to work in the concept of that ratio decreasing as the height of the column increased. There were no fabricators in the Texas area, or in the United States that believed they could complete the task, and so the designers looked to Europe. The only fabricator that they could find to do this task properly was located in Holland, in the Netherlands [141]. So, the interior column was created there and shipped from Holland to Austin, a total of 5,099 miles according to Google Maps. Looking into the future of this column, any maintenance concerns will most likely need to be taken up with the Dutch fabricators, and if parts need to be replaced, those will probably need to make the 5,099-mile journey again.

Picture 13: Dutch Column in the EER

[141] Avantsa.

That being said, I believe there is an element of beauty that comes with the use of the Dutch column. At least in the immediate Central Texas area there is nothing else like this, which gives the column that 'wow' factor. It is beautifully constructed and students, professors, engineers, and architects alike can appreciate its design, simplicity, and original intention. The point I want to emphasize, however, is that we need to consider the mal-effects that this beauty has caused our environment. In another scenario, maybe the designers would have considered changing their design to find something locally procured that would have had a similar effect on those who interact with it.

The reason I say this is because of a concept called 'embodied energy', that I believe has an underlying goal of promoting the use of locally procured materials as compared to those from overseas or far away. It is defined as "the total energy required for the extraction, processing, manufacture and delivery of building materials to the building site" [142] and can be broken down into two areas of study and measure, initial embodied energy and recurring embodied energy. Initial embodied energy is "the non-renewable energy consumed in the acquisition of raw materials, their processing, manufacturing, transportation to site, and construction" [143] and recurring embodied energy is "the non-renewable energy consumed to maintain, repair, restore, refurbish or replace materials, components or systems during the life of the

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[142] BRANZ Ltd, "What Is Embodied Energy in Building?," August 5, 2018, http://www.level.org.nz/material-use/embodied-energy/.

[143] "Measure of Sustainability Embodied Energy," Design Magazine, Canadian Architect, accessed April 17, 2018, https://www.canadianarchitect.com/asf/perspectives_sustainibility/measures_of_sustainablity/measures_of_sustainablity_embodied.htm.

building"[144]. As with other forms of energy production, the creation of embodied energy releases CO_2, which is a greenhouse gas that contributes to global climate change. For this reason, embodied energy is considered by designers and engineers when looking at what materials to choose for a building.

It should not be viewed as an absolute, rather as a reference point as there are other factors that play into the environmental impacts associated with materials and construction. No extensive measurements have been taken on embodied energy, but based off what has been done, common units of measurement are MegaJoules and GigaJoules per area of material or per unit weight of material [145].

But what is accounted for when measuring embodied energy? How would one know if the embodied energy of a material, say pinewood, coming to Austin from Washington would be higher than that of the same pinewood coming from Oklahoma? From the definition of embodied energy, one can see that the energy for extraction of materials plays a part, as does the time and energy spent on processing the material. The delivery of the material to the construction site is the last main factor, and this considers how far the material had to drive, sail, or fly from its point of origin. If the aforementioned pinewoods were to be compared, the following results would be concluded. Let's assume the pinewood is coming from Seattle and

[144] "Measure of Sustainability Embodied Energy."
[145] Ltd, "What Is Embodied Energy in Building?"

from Oklahoma City. [146] [147].

Table 1: Comparing Embodied Energy of Pinewood from Washington and Oklahoma

Embodied Energy Factors	Washington Pinewood	Oklahoma Pinewood
Energy of Extraction	Pinewood is abundant, and many species of pine trees are scattered throughout Washington State [148]	Pinewood is not as common a tree in Oklahoma, so it would take more time and resources to find this kind of tree [149]
Processing	Pinewood would be cut, sanded, and formed into its desired shape. There might be processors who specialize in processing pinewood in Washington since it is such a common tree	Pinewood would be cut, sanded, and formed into its desired shape. It could be harder to find a processor who can properly process the pinewood
Transportation	The distance from Seattle to Austin is around 2,128 miles according to Google Maps.	The distance from Oklahoma City to Austin is around 338 miles according to Google Maps.
Maintenance	Process repeated, from procurement, to processing, to transportation. Quality of the pinewood would determine how often this needs to happen.	Process repeated, from procurement, to processing, to transportation. Quality of the pinewood would determine how often this needs to happen.

From the table, one can see the calculation of embodied energy has many factors that play a part. Using the different sub-definitions of embodied energy, the energy of extraction, processing, and transportation would fall under ‘initial’ embodied energy, while maintenance

[146] Darla Slipke, “Five of the Most Common Trees in Oklahoma City Parks,” News, NewsOK, March 24, 2017, https://newsok.com/article/5542906/five-of-the-most-common-trees-in-oklahoma-city-parks.
[147] Milton Mosher and Knut Lunnum, “Trees of Washington,” Educational (Washington State University, November 2003), http://cru.cahe.wsu.edu/CEPublications/eb0440/eb0440.pdf.
[148] Mosher and Lunnum.
[149] Slipke, “Five of the Most Common Trees in Oklahoma City Parks.”

would fall under recurring embodied energy. Like mentioned in Table 1, the quality of the wood will determine the frequency of repair and maintenance costs, as will what it is being used for. This proves that embodied energy is not an 'end-all-be-all,' rather just one measure of the environmental impact of a material. Embodied energy must be compared to the performance and durability of a material since this might make the pinewood, in this case, more or less likely to be a suitable choice for a specific task [150].

To get a numeric value for the embodied energies associated with each kind of wood, many factors would play into the final value. These are: the implications of resource depletion, greenhouse gasses, environmental degradation, and reduction of biodiversity. It also accounts for the energy to obtain the material and assemble the structure [151]. The following table shows the embodied energy for some of the most common building materials and has been adapted from the Canadian Architect, the official magazine of the Royal Architecture Institute of Canada[152].

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[150] Iyyanki Muralikrishna and Valli Manickam, "Environmental Management: Science and Engineering for Industry," in *Environmental Management: Science and Engineering for Industry*, 2017, https://www.sciencedirect.com/science/article/pii/B9780128119891000051.
[151] "Measure of Sustainability Embodied Energy."
[152] "Measure of Sustainability Embodied Energy."

Table 2: Embodied Energy Associated with Certain Building Materials

Material	Embodied Energy	
	MJ/kg	MJ/m^3
Aggregate (to be used in concrete production)	0.1	150
Soil-cement	0.42	819
Local Stone	0.79	2030
Concrete block	0.94	2350
Precast concrete	2	2780
Lumber	2.5	1380
Brick	2.5	5170
Gypsum wallboard	6.1	5890
Aluminum (recycled)	8.1	21870
Aluminum (not recycled)	227	515700
Steel (recycled)	8.9	37210
Steel (not recycled)	32	251200
Asphalt shingles	9	4930
Plywood	10.4	5720
Glass	15.9	37550
Copper (for wire insulation)	70.6	631164
PVC	70	93620
Synthetic carpet	148	84900
Paint	93.3	117500

Applications of Embodied Energy

Embodied energy is not an easy concept to attach a number to. Even with Table 2, there are many factors associated with the study that make it specific to one region of the world, and to one method of transportation. This means engineers erecting a building in South America would not be able to use the numbers mentioned earlier because they only apply to one region of Canada. It tends to be a very pointed study that requires researchers to narrow their scope, making it hard for generalizations to be made.

Given this, there are researchers who have taken up this field of study, and have focused on different methods to evaluate embodied energy in different contexts, from the food system, textiles and apparels, to building materials. Two methods I will focus on are called Life Cycle Analysis (LCA) and one of its subsects, called Energy Input-Output (EIO). LCAs have been used for decades in the context of evaluating "all the inputs and outputs throughout the life cycle of that product, from its birth, including design, raw material extraction, material production, part production, and assembly, through its use, and final disposal" [153] [154]. Because they have been used for a long period of time, there is a precedent of what to expect and how to go about conducting these analyses.

The second model I'll talk about, the EIO model, was invented around the same time by a Nobel Prize winning economist named Wassily Leontier [155] and has more recently been elaborated on by other parties like researchers at Carnegie Mellon University in the 1990s.

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[153] The Environmental Literacy Council, "Life Cycle Analysis," Informational, The Environmental Literacy Council, 2015, https://enviroliteracy.org/environment-society/life-cycle-analysis/.
[154] Scientific Applications International Corporation, "LIFE CYCLE ASSESSMENT: PRINCIPLES AND PRACTICE" (NATIONAL RISK MANAGEMENT RESEARCH LABORATORY, May 2006), https://www.e-education.psu.edu/egee401/sites/www.e-education.psu.edu.egee401/files/A%20Brief%20History%20of%20Life-Cycle%20Assessment.pdf.
[155] "Economic Input-Output Life Cycle Assessment: About The EIO-LCA Method," University, Carnegie Mellon University, 2016, http://www.eiolca.net/Method/index.html.

Life Cycle Analysis method

Life Cycle Analysis is a method used to assess the full life of an item, from "cradle to grave" as some professionals will call it [156]. In other words, it is a good estimate of everything a material has been through from its fabrication or harvesting till its final use. The four main steps involved in this model deemed by the International Organization for Standardization (ISO) are called Goal and Scope, Inventory Analysis, Impact Assessment, and Interpretation [157]. Step 1 puts a timeline on the assessment, defining a beginning and end. The aim of the LCA is also defined in this step [158]. Next, step 2 looks at the material based on interactions with the environment, consumed raw materials, and emissions given off [159]. This is the step that the EIO model tries to expand upon. Step 3 of the LCA evaluates the information from step 2 and translates it into overarching environmental themes, like public health and climate change [160]. Finally, the last step of an LCA is the interpretation stage, where results are checked once more for accuracy, and then turned into a report [161]. These steps and how they relate to one another are shown in Figure 14.

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[156] Iyyanki Muralikrishna and Valli Manickam, "Environmental Management: Science and Engineering for Industry," in *Environmental Management: Science and Engineering for Industry*, 2017, https://www.sciencedirect.com/science/article/pii/B9780128119891000051.
[157] Muralikrishna and Manickam.
[158] Muralikrishna and Manickam.
[159] Muralikrishna and Manickam.
[160] Muralikrishna and Manickam.
[161] Muralikrishna and Manickam.

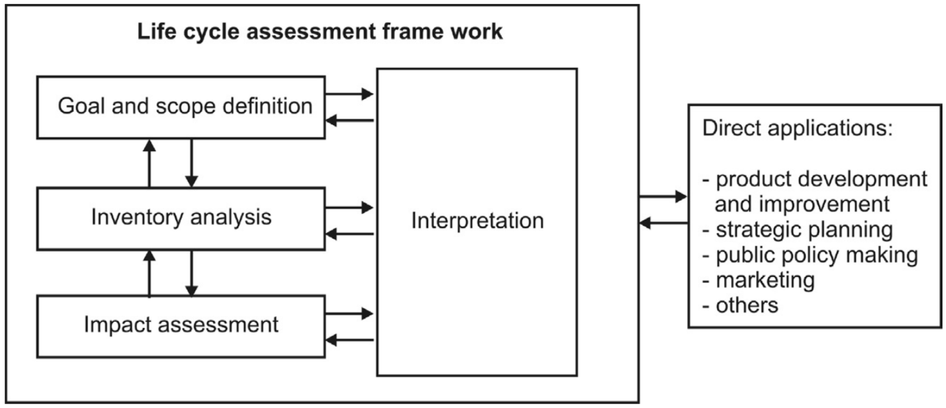

Figure 14: Steps Associated with the LCA model [162]

As an example of this, we can look at the LCA of lumber and of concrete. Lumber would be assessed on the categories of where it was harvested from, how much manual labor went into cutting, sizing, and sanding down the edges, and what kind of protective coating was used. Concrete would be assessed on the categories of what kinds of aggregates were used, how much water was used, if Supplementary Cementitious Materials made it into the mix, and so forth. The point of comparing these two is to show that LCAs are material specific, and thus have very discrete categories that only apply to the material in question.

A full LCA study that I found while researching this topic was conducted in Madrid, Spain. It looked at the estimated embodied energy of common building materials used in Madrid by conducting LCAs. In the study, a group of researchers picked a set of standard materials and

[162] Muralikrishna and Manickam.

looked at their energy intake and CO_2 emissions over time, specifically taking note of the initial energy intake [163].

In the study, they found that each meter square of gross floor area constructed emitted about 0.5 tons of CO_2 and had an average energy consumption around 5754 Mega Joules [164]. Figure 15 shows the primary energy demand required to construct one meter square of floor area from the researchers' findings. It breaks up the total energy required into percentages to show how much each material was responsible for. Figure 16 highlights the CO_2 output that the same group of materials were responsible for over the entire construction period of one meter square. The reason these pie charts and findings are significant is because it shows the impact broken down material, which can help us understand which materials in regular construction emit the most CO_2.

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[163] Ignacio Z. Bribián, Antonio V. Capilla, and Alfonso A. Usón, "Life Cycle Assessment of Building Materials: Comparative Analysis of Energy and Environmental Impacts and Evaluation of the Eco-Efficiency Improvement Potential," *Science Direct*, Building and Environment, 46 (December 9, 2010): 8, https://doi.org/46 (2011) 1133e1140.
[164] Bribián, Capilla, and Usón.

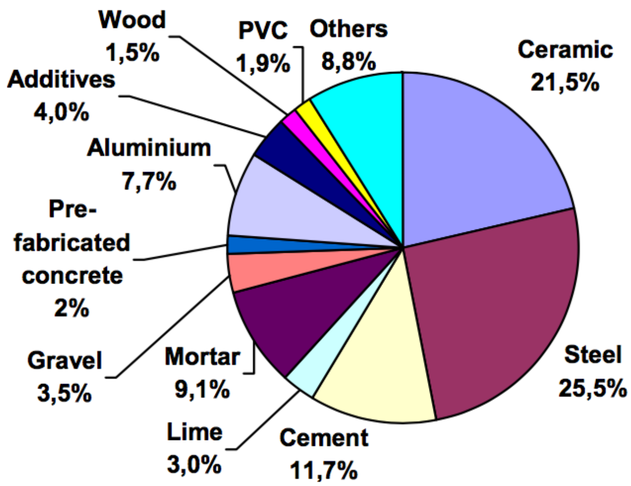

Figure 15: Contribution of primary energy demand for the manufacture of the materials needed in the construction of 1 m^2 (gross floor area) [165]

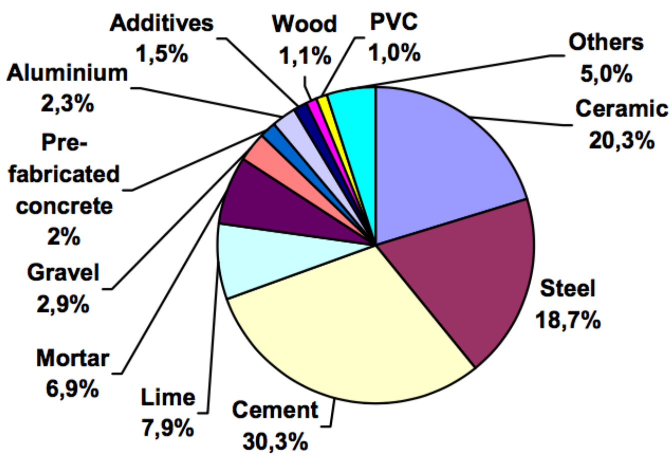

Figure 16: Contribution of CO_2 emissions associated with the manufacture of the materials needed for the construction of 1 m^2 (gross floor area) [166]

[165] Bribián, Capilla, and Usón.
[166] Bribián, Capilla, and Usón.

Energy Input-Output method

The EIO model has a few different acronym meanings, but the same methodology of analysis. There is the Energy IO (Input-Output), the Economic IO, and sometimes the Environmentally-extended IO. At the base of it all, they are mathematical methods of "using economic and environmental data to determine the effect of changing the output of a single sector" [167]. This means that they hone in on one variable and look at how it changes when other variables are changed. The variable that is most often kept constant is cost [168].

As an example, we can imagine the same case from earlier where lumber and concrete need to be compared. In the EIO model, chances are that cost would be the variable that is monitored for both materials. The methodology would be to look at how each material is procured, processed, and transported, and tie a cost to each phase. For lumber, this would mean determining the cost of cutting a tree down and the cost of processing that lumber and making it suitable for construction (cutting, cleaning up the edges, painting a protective coating, making it insect-proof, etc.). For concrete, the cost of obtaining raw materials to make final concrete and the cost of manufacturing and letting the concrete set in acceptable conditions would be considered. Transportation and manual labor would factor in for both.

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[167] Scientific Applications International Corporation, "LIFE CYCLE ASSESSMENT: PRINCIPLES AND PRACTICE" (NATIONAL RISK MANAGEMENT RESEARCH LABORATORY, May 2006), https://www.e-education.psu.edu/egee401/sites/www.e-education.psu.edu.egee401/files/A%20Brief%20History%20of%20Life-Cycle%20Assessment.pdf.

[168] Catherine Birney, Conversation with Catherine Birney, In-person, April 3, 2019.

EIO methods make use of matrices and multiple levels of variables to properly analyze the variable in question. Due to this, calculations can be mathematically demanding as they need to account for the direct, indirect, and industry demands [169]. This is sometimes seen as a disadvantage of the EIO model as it is highly involved.

Using this Information

There have not been many LCAs or EIOs carried out on building materials that consider embodied energy, but looking at studies that reflect CO_2 emissions, greenhouse gas emissions, waste by-products, and water intake are good ways to get an idea of associated embodied energies. Moving into the future, I hope to see an increased number of these models created to look at building materials and their impact on the surrounding environment. They can use information from "industry transactions … and the information about direct environmental emissions of industries, to estimate the total emissions throughout the supply chain" [170] to have a basis of comparing different materials.

A point that was made in almost all reports I read, as well as in conversations I had about this topic was about transportation. Transportation costs have such a large impact on the embodied energy metric, and this is a reason that I believe local materials are smarter to use than

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[169] Zeus Guevara and Tiago Domingos, "The Multi-Factor Energy Input–Output Model," *Science Direct*, Energy Economics, 61 (December 9, 2016): 9, https://doi.org/(2017) 261–269.
[170] "CMU."

international ones [171] [172] [173]. Since local materials come from shorter distances, they have less associated transportation emissions when compared to international materials coming from different parts of the world. International materials might seem like the cheapest alternative upfront, but they can end up having high operating and maintenance costs [174]. Compared to them, local materials reduce the total embodied energy metric and I speculate can even potentially reduce maintenance costs.

In Austin and Antigua, there have not been sufficient studies done on the embodied energies of materials. Studies from other areas with similar natural resources can be used as an estimate to see how the cities fare in terms of using materials with a low embodied energy. The study mentioned earlier of impacts of common building materials in Madrid is a good parallel that can be used in both cities as Antigua makes common use of ceramics, Austin makes extensive use of steel, and both use cement in concrete production [175]. Other materials that are common in Austin and Antigua that have been analyzed in this study are adobe, lumber, and hollow concrete bricks.

From the Madrid study, the researchers came out with findings about the five aforementioned materials. On adobe, they found that adobe has a high associated embodied energy, but also

[171] Birney, Conversation with Catherine Birney.
[172] Isabella Gee, "Referred from Maria Juenger," April 1, 2019.
[173] "Measure of Sustainability Embodied Energy."
[174] Bribián, Capilla, and Usón, "Life Cycle Assessment of Building Materials: Comparative Analysis of Energy and Environmental Impacts and Evaluation of the Eco-Efficiency Improvement Potential."
[175] Viviana, Email with Bindy Viviana.

that it “reduces the embodied energy in the life of the building between 1.5 and 2 times compared with conventional materials”[176]. This overall reduction is because of the materials that go into creating the adobe, which these researchers cited as “low energy intensive materials like soil, sand, cow dung, etc.” [177]. Life cycle here is taken to be a period of 50 years. With respect to lumber, they found that “wooden structures require less energy and emit less CO_2 during their life cycle than buildings with other types of structures”[178], ‘structures’ here referring to traditionally international materials. Finally, they talked about hollow concrete blocks as an alternative material to the traditional Concrete Masonry Units and reinforced concrete, saying that the small swap “could save 20% of the cumulative energy over a 50-year life cycle” [179]. The research that this claim is based off was done by Huberman and Pealmutter and their studies on building materials in desert architecture. Unfortunately, The University of Texas system did not have the permission required to read the full report, so I submitted a request and have not received the go ahead yet. Once I have permission, I believe it will be useful to read this report and further understand how Huberman and Pealmutter drew their conclusion, but for now I wanted to mention it in this thesis to show the potential benefits of choosing environmentally friendly materials.

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[176] Bribián, Capilla, and Usón, “Life Cycle Assessment of Building Materials: Comparative Analysis of Energy and Environmental Impacts and Evaluation of the Eco-Efficiency Improvement Potential.”
[177] Ashish Shukla, G.N. Tiwari, and M.S. Sodha, “Embodied Energy Analysis of Adobe House,” *Science Direct*, Renewable Energy, 34, no. 3 (October 21, 2016): 755–61.
[178] Bribián, Capilla, and Usón, “Life Cycle Assessment of Building Materials: Comparative Analysis of Energy and Environmental Impacts and Evaluation of the Eco-Efficiency Improvement Potential.”
[179] Bribián, Capilla, and Usón.

Further Research and Conclusion

Further Research

As mentioned in the Environmental Input-Output section, I believe a way for embodied energy research to move forward is by creating EIO models that compare embodied energy of materials against one another, in lieu of cost. This can be broken up even further to compare differences in initial embodied energy and recurring embodied energy. Given the grand potential that embodied energy can have on the fields of materials research, design, and construction, I believe there needs to be more work done to fully understand the concept and create standards.

In the current codes we use today, there are design guidelines specific to different common building materials, for example those put out by the American Concrete Institute (ACI), the American Institute of Steel Construction (AISC), and the American Society for Testing and Materials (ASTM), which are popular within and outside of the United States. These help designers pick materials and design for safety. When trying to find guidelines on what kind of environmentally conscious materials to use, there are a few guides like the U.S. Green Building Codes and LEED which try to promote choosing materials that will reduce the adverse effects materials could have on the environment [180]. A shortcoming of LEED is that they work on a point system, a certain number of points earning the building a gold/silver/platinum/certified status. The total number of points for a building to earn is 110, and only 6 of these relate to

[180] USGBC, "Green Building Codes," U.S. Green Building Council, 2019, https://new.usgbc.org/green-codes.

material selection, none of which mention the term embodied energy [181]. It is such a small fraction of points that it is easy to overlook.

A main concern with these guides is that they are initially considered for material selection, but might be outweighed by cost at the end of the day. In my experience in industry, a common way to design buildings and choose materials was to look at what was done in the past and mimic it. But what should we do if the older, 'standard', buildings make use of environmentally inefficient materials?

Once the initial material selection has been made, the question of where to source the material comes up. Some big questions that might be asked are: what is the cheapest option, what vendors have been used in the past; are there preexisting relationships between suppliers and designers, and how far will the material be transported. On the other hand, some big questions that might not be asked, or are likely just given less weight are: what does maintenance and repair of this material look like, how many vehicles will be needed to transport the amount of material needed, is there a local material that has the same aesthetic and engineering properties, and what is the embodied energy associated with using this material.

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[181] USGBC, "Building Product Disclosure and Optimization - Sourcing of Raw Materials," U.S. Green Building Council, November 2013, https://www.usgbc.org/node/2616388?return=/credits/new-construction/v4/material-%26amp%3B-resources.

I believe a few reasons that these questions are not always asked is because our nature is to save money and go with the cheapest option, at least based on initial cost. For example, if a new project was going up in Dallas that required large quantities of limestone, and contractors had a choice between more expensive limestone from Central Texas and less expensive limestone from Indiana, they would most likely go with Indiana limestone. As counterintuitive as it may seem, in a conversation I had with Larry Speck, he told me that something like this happened to him, where limestone was transported in from the Midwest instead of just using the natural deposits present in Texas. But something to keep in mind with this decision-making process is that the cheapest material might require the most maintenance, meaning frequent recurring costs, importing materials repeatedly, and thus an increased amount of greenhouse gas emissions.

This all begs the question of why there isn't a rule that says people should save the miles, gas, fossil fuels, and greenhouse gas emissions and go with an option that is the least harmful on the environment [182] [183]. A big reason why there is no standard in place to measure the embodied energy of building materials is because it is such a huge task to tackle. Embodied energy considers so many specific factors for each building material that trying to create a standard would be very difficult. Cost of raw material varies in different areas, as does the cost of manufacturing and production, and the price of gas. There would be many adjustment factors

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[182] Jenny Green, "Effects of Car Pollutants on the Environment," *Sciencing*, March 13, 2018, https://sciencing.com/effects-car-pollutants-environment-23581.html.
[183] Christina Nunez, "Fossil Fuels, Explained," *National Geographic*, April 2, 2019, https://www.nationalgeographic.com/environment/energy/reference/fossil-fuels/.

needed if one were to create a single standard for this issue. But just because something seems hard doesn't mean it shouldn't be done.

There was a company called Air Quality Science (AQS), which was recently absorbed into Underwriters Laboratories (UL), that was created under similar circumstances. These circumstances were the need to learn more about what level of pollutant emissions were associated with different kinds of interior furnishings, and what effect these pollutant emissions were having on the ambient air quality in a room. There were no standards at the time as to what was allowed, so a team decided to take it upon themselves and solve the problem by looking at these pollutant emissions themselves [184]. They called themselves Air Quality Science and made such a respected name for themselves that UL decided to team up with AQS, giving their stamp of approval even more weight [185]. Together, they call themselves UL AQS and have partnered with multiple third party organizations "including GREENGUARD, Green Label Plus, Green Seal, EcoLogo, CHPS, UL Environment, Blue Angel, and USGBC" [186] to offer certification services in testing their products for pollutant emissions. They've even made it to an international scale, offering to test products for European groups, as well as the Green Building

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[184] Lawrence Speck, Converastion with Larry Speck, In-person, April 10, 2019.
[185] Underwriters Laboratories, "Underwriters Laboratories Teams Up with Air Quality Sciences to Certify Products for New Ozone Emission Standards," Press Release, Underwriters Laboratories, August 14, 2008, https://news.ul.com/news/underwriters-laboratories-teams-air-quality-sciences-certify-products-new-ozone-emission.
[186] Underwriters Laboratories, "UL AQS Achieves Accreditation for Indoor Air Quality Emissions Testing to the Newest Blue Angel Standard for Electronic Imaging Devices," Press Release, Underwriters Laboratories, September 20, 2012, https://news.ul.com/news/ul-aqs-achieves-accreditation-indoor-air-quality-emissions-testing-newest-blue-angel-standard.

Council in Singapore [187]. From a group of people seeing a need in their community and acting on their idea, they have impacted the world in a positive way, ensuring that building codes and standards account for ambient air quality and emissions. They have also created a positive connotation for having a 'UL AQS' certified product, which I expect encourages companies to seek this out to increase their creditability.

Taking what AQS did with ambient air quality, I see something very similar developing that focuses on embodied energy. We are currently in a similar situation where embodied energy is not being taken seriously within codes and industry, just as pollutant emissions were once not. In the wake of climate change, I believe that embodied energy needs to be studied in greater depth to develop a true understanding of what is happening in present day, and then to see how we can improve it by discouraging the use of high embodied energy materials. This will be time and energy intensive, but I believe that a team of dedicated researchers would be able to develop a set of standards, and I would love to be a part of that change. It is an important indicator of if a material should be used or not, and I believe it has the potential to reduce our carbon footprint.

[187] Underwriters Laboratories, "UL AQS Offers U.S. Manufacturers the Ability to Test to New European Product Emissions Standards," Press Release, Underwriters Laboratories, July 25, 2012, https://news.ul.com/news/ul-aqs-offers-us-manufacturers-ability-test-new-european-product-emissions-standards.

Conclusion

Although Austin and Antigua are approximately 1644 miles apart according to Google Maps, they still have much in common. The two have a shared history of being under Spanish rule, and having some of their material and city planning preferences still in place today. Both cities have booming coffee cultures; Antigua being home to some of the biggest coffee farms in the country and Austinites loving to drink the caffeinated beverage [188] [189]. Finally, both cities have an abundance of regional materials around them that have the potential to be used in building construction in lieu of imported ones.

As has been outlined in this thesis, the main basis of my argument to use local materials because of the benefits seen when comparing them to international materials. Most of these benefits can be studied based on the term 'embodied energy', which is the cumulative energy that went into the "extraction, processing, manufacture and delivery of building materials to the building site" [190] and is mainly made up of initial and recurring embodied energy. Initial embodied energy refers to the primary energy consumed in the process of sourcing the material and prepping It for use [191]. Recurring embodied energy refers to the maintenance and upkeep costs that are associated with that material [192].

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[188] Anderson et al., "Guatemala."
[189] Joanne Xu, "Austin Coffee Shop Culture," *Orange Magazine*, April 7, 2017, https://orangemag.co/pulp-1/2017/4/7/atx-coffee-shop-culture.
[190] Ltd, "What Is Embodied Energy in Building?"
[191] "Measure of Sustainability Embodied Energy."
[192] "Measure of Sustainability Embodied Energy."

Embodied energy is related to both water consumption and CO_2 output, in addition to other variables, as these are main indicators of what goes into creating a material as well as what impacts the material will have on its surroundings [193] [194]. And since there are not many studies currently out that focus on just embodied energy in specific materials, research that talks about CO_2 emissions and water intake are good indicators of how a material fares in terms of associated embodied energy.

Two reliable methods of analyzing CO_2 emissions, water intake, and thus embodied energy over the course of a material's use are called the Life Cycle Analysis (LCA) model and the Environmental Input-Output (EIO) model. LCAs look at the material from its birth till final disposal [195]. In other words, it analyzes the material from its extraction or creation until it reaches the job site; the destination. EIO models are a variation of LCAs, and they are good for grouping items together and comparing them based on a single factor. They look at materials and assign monetary values to each step it goes through on its way to being used on a job site, in order to create an equal basis of comparison [196].

A lot of effort goes into selecting building materials. Architects, engineers, and clients must agree. The material must prove to be structurally sound and aesthetically pleasing, as well as adhere to requirements like fire ratings and pollutant emissions. Multiple sources may be

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[193] Birney, Conversation with Catherine Birney.
[194] Donna Kacmar, "Referred from Prof. Larry Speck," February 15, 2019.
[195] The Environmental Literacy Council, "Life Cycle Analysis."
[196] Birney, Conversation with Catherine Birney.

considered until the best option for procurement is found. Depending on the area in which the building is going up, there might be material specifications on what can and can't be used. If it's for restoration purposes, the new material must match the old one. Essentially, this process can take a while.

An idea that has the potential to speed up the material selection process by recommending certain materials over others is a standard based on embodied energy. The way I see it, it would not mandate what materials to use, rather just provide guidelines to make the decision easier and faster for designers. This could be done by setting a maximum allowable embodied energy limit, and by working with designers or material manufacturers to ensure that they are creating suitable building materials in a way that reduces embodied energy. AQS works through both of these methods and would act as a good guide when setting embodied energy criteria [197].

Finally, let's take a quick look at the next generation of ideal homebuilders. 20 or 30 years down the line, imagine a couple trying to design their own home in Central Texas. Assume they want to design for this home to last, and have a minimal mal-effect on the environment. The landscape calls to them, and because of this, they want to make use of the stones and limestone that is present throughout Central Texas. This gives them a sense of connection to the area since many other homes use them as well, and they want their future kids to grow up having this connection, this sense of belonging to Central Texas. To make sure that they are

[197] Underwriters Laboratories, "UL AQS Achieves Accreditation for Indoor Air Quality Emissions Testing to the Newest Blue Angel Standard for Electronic Imaging Devices."

being environmentally conscious builders, the couple gets in contact with the contractor they're working with, and together, they look up the embodied energies of the materials in question. After some discussion, the group decides to move forward with the local materials as those have the lowest associated embodied energies. They double check that the total embodied energy of their home does not exceed the maximum allowed limit outlined in the building codes, and move forward once they discover it does not. This here is the idealistic vision I have for the future of embodied energy. It has the potential to integrate into building codes, aiding homebuilders make smart and environmentally conscious decisions.

Biography

Aparna Chandrashekar was born in Cleveland, Ohio on September 19, 1995, and moved quite a bit growing up, living in Cleveland, Singapore, Bangalore, and finally Austin. She enrolled in the Plan II Honors program at the University of Texas at Austin in 2014 and studied Civil Engineering in tandem. She participated in a Maymester to Vienna, Austria, an engineering research exchange in Santiago, Chile, and a semester exchange in Madrid, Spain. She was involved with civil engineering groups like ASCE, Chi Epsilon, and Projects with Underserved Communities, as well as a service and social group called Texas Spirits. Aparna is planning on working in Historic Preservation in Washington, D.C., starting in the Fall of 2019.